OLIVER LODGE AND THE ORIGINS OF SPARK TRANSMISSION

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The origins of radio are intimately bound up with the use of sparks for generating electromagnetic waves. This has important implications for the forms of early transmitters and receivers. At the beginning of the era it was not known whether such waves existed, how to generate them or how to detect them. The advances achieved were very much the product of complementary developments along all three lines.

BACKGROUND

James Clerk Maxwell set the process in motion by attempting to unify the various electrical and magnetic dicoveries of the preceding era particularly those of Michael Faraday. Much of this was inherent in his papers of 1861-5 and expanded and developed in his "Treatise on Electricity and Magnetism" of 1873, but it was left to others, particularly Oliver Heaviside, to make the implications explicit and to express the mathematics in a more concise form (O'Hara and Pritcha, 1). In Germany the implications were not fully accepted and Hermann L.F. Helmholtz in particular felt that immediate "action at a distance" was more probable than the finite velocity of propagation implied by Maxwell. He felt that this could be tested by investigating the extra or displacement current required by Maxwell and set Heinrich Hertz on testing this (Hertz and Susskind, 2).

Meanwhile Oliver Lodge, Professor of Physics at Liverpool and his friend George Francis FitzGerald at Dublin were corresponding on the possibility of generating such electromagnetic waves by discharging a Leyden jar. FitzGerald at first denied the possibility but later reversed his decision - a delay which Lodge later felt could have robbed him of the priority in the discovery of electromagnetic waves (Lodge, 3). As it was, their results came out concurrently but the waves of Hertz were in free space whereas those of Lodge were guided by wires. Furthermore the experiments of Hertz were more exhaustive, both because he was a painstaking and methodical worker and there was a less favourable climate of opinion in Germany (2). Lodge on the other hand, thought of himself as the "armchair scientist" devising "the crucial experiment" and often leaving it to his assistants to perform (3). Nevertheless Lodge did have a important part to play in the evolution of radio (Rowlands and Wilson, 4).

Oliver Joseph Lodge was born in 1851 at Penkhull, Stoke-on-Trent, and was coerced into working for his father in the sale of pottery materials. He had to study in his spare time but was eventually released to study in London, gaining his DSc at University College London in 1877. After continuing research with Carey Foster on electric current paths in conducting surfaces, electrolytic conduction and thermoelectric effects he was appointed first Professor of Physics at Liverpool in 1881.
His early experiments at Liverpool were practical in nature and concerned ionic conduction, lead-acid batteries, photoelectricity and the electrostatic precipitation of dust (Rowlands, 5). The last provided a most entertaining lecture at the BA Meeting in Montreal in 1884. News of this got to Dr Alfred Walker of the Deeside Lead Works who consulted Lodge on the feasibilty of removing lead from the flue gases more effectively. Initial trials using 5ft. Wimshurst machines were successful but the venture failed ultimately (Lodge, 6). After his development of valve rectifiers and various experiments with fog dispersal, Lodge was able to apply these ideas through his sons Lionel and Noel who with W. F. Newman, set up the Lodge Fume Deposit Co. Ltd. which, after several changes of name is still in business today (4).

The work which really forms the prelude to the development of radio is that on lightning conductors. Lodge was invited by the Society of Arts to give two lectures in March 1888 in honour of Dr Robert Mann, who had been an enthusiatic advocate of lightning rods in South Africa, and set about a series of experiments to test his ideas in this direction. What Lodge immediately saw as flawed was the idea that Ohm's law was all that was required to describe a lightning conductor. He knew of the effects of inductance from his boyhood experiments in Hanley (3). He also knew from the experiments of others that the discharge of a Leyden jar was oscillatory. He concluded that lightning discharges would also be oscillatory (Lodge, 7), but in this he turned out to be wrong as multiple strikes are a series of independent unidirectional transients (Golde, 8). Nevertheless the inductance of a lightning conductor will develop a potential across it of Ldi/dt, greatly exceeding iR. In preparation for these lectures Lodge performed many experiments to illustrate and explain the vagaries of lightning and they were a great success. As a result he was invited to debate the issues at the BA Meeting in Bath. Lodge the outspoken scientist, and 10 years the junior, clearly offended Preece the practical man with 50,000 lightning conductors in his charge, and later payed for it dearly (4).

EXPERIMENTS ON SPARKS AND THE GENERATION OF ELECTROMAGNETIC WAVES

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These were started with the collaboration of his demonstrator Arthur P. Chattock and assistant Edward Robinson in February 1888 (5). They used a Voss machine (a predecessor of the Wimshurst) and a variety of capacitors ranging from sliding tube condensers, 90-500pF, through Leyden jars, 240pF to 6.3nF, to "double thickness window glass condensers", 0.028μF (Lodge, 9). These were all compared with a carefully constructed standard guard-ring capacitor using a ballistic galvanometer. Five loops of wire each about 30m long were slung around the laboratory on silk threads, ranging from 1 S.W.G. copper (0.025 ohm) to 27 S.W.G. iron (33 ohm).

Alternative Path

In this experiment a spark could occur in either of two routes and by adjustment of one of the spark gaps could be made to choose that path on 50% of trials; the length of this gap then provided a baseline measure. The primary spark normally occurred at the terminals of the Voss machine labelled "A" and that elsewhere labelled "B" (Fig. 1). What this experiment demonstrated was that the current frequently sparked across at B in preference to silently passing round a low resistance loop. Thus the impedance of the spark path was less than that of the loop, owing to the latter's inductance.

Overflow

This refers to a number of experiments in which Leyden jars "overflow" by sparking from one tinfoil coating to the other over the lip of the jar. The significant feature being that the overflow path is frequently much longer than that of the A spark. This was particularly true when a very long loop was used to connect the jar (Fig. 2). This would appear to be due to magnifying effect of a high-Q circuit in which a potential applied in series with an inductor and capacitor produces a larger potential across them. Lodge felt that it was somehow due to the small inductance of the overflow path although he also recognised that sharp edges and contamination could contribute.

A and B Sparks

In a Wimshurst machine the A spark normally occurs between the knobs connected to the inner coatings of a pair of Leyden jars which accumulate sufficient charge to provide an energetic discharge. Humidity or dirt in this part of the equipment would provide a leakage path that would prevent the charge building up. The outer coatings of the jars rest on a wooden base which would normally form a leakage path to earth and are connected together. If, however, a short break is made in this connection it will be bridged by the B spark every time an A spark occurs. The potential across this B gap remains at zero until the A spark occurs. Leakage at this point is irrelevant to the spark, and indeed is neccessary for charging the jars. Such a spark is often fatter and brighter than the A spark and can occur in the presence of contamination or even under water. Lodge later realised that this would form an ideal basis for a car ignition system and with his third son Alec patented it in 1903 (Lodge and Lodge, 10). They had it manufactured for them by the Muirhead Co., based on an induction coil rather than an electrostatic machine (4). Armed with the "Lodge Igniter", Alec as engineer and Brodie (second son) as business manager, formed "Lodge Bros." (later to become "Lodge Plugs"). Variants of the device are still used today for industrial ignition and jet engine igniters, but it was the spark plugs which produced the profits.

Lightning Strikes

Lodge set up two metal trays and put a number of articles between them to represent various targets for lightning strikes (9). These were of differing heights with rounded or sharp extremities, some good conductors such as metal, others poor such as a column of water, and also a gas flame to represent a smoking chimney. He found that the order in which they were struck was different according to whether the trays were charged gradually like an A spark or impulsively as a B spark. For A (Fig. 3), small knobs got struck in preference to large ones, points were not struck because they discharged silently, and the resistive path made the spark "soft and velvety". For the B spark condition (Fig. 4), shape became irrelevant, the nearest item receiving the discharge, although sometimes more than one item was struck at once. The resistive path was never taken even when completely bridging the trays and the gas flame got struck at a much greater distance than the metallic objects. Lodge patented various lightning guards which were marketed by the Muirhead Co.

Side Flash

In this arrangement a subsidiary circuit, connected at only one point to the main one, frequently showed a discharge (Fig. 5). The term "surging circuit" was also applied to this condition. This effect has been observed in lightning conductors as sparking where it would not normally be expected. It appears to be related to the "recoil kick" in which wave motion occurs along wires.

Recoil Kick

The "recoil kick" was first noted by Mr. Chattock in Lodge's absence on March 1, 1888, and was interpreted by him as evidence of a standing wave. This is the most important observation from the point of view of this paper as it presents the first evidence of radio waves as far as Lodge was concerned. The experiment takes the form of a parallel pair of the 30m wires fed from a Voss machine with a bridging spark gap, B, set at various positions along the length of the wires (Fig. 6). If the spark gap is set close to the A spark at B1, it sparks at much the same separation, but if situated at the remote end, B3, it can be 2-3 times longer. When the separation exceeded that at which sparking could be obtained, the ends of the wires sometimes took on a luminous appearance in the dark, gradually fading off towards B1. Both effects were interpreted as evidence of standing waves. Lodge tried various capacitors at A and found that some of them were better tuned to the length used. He calculated the various inductances and capacitances and concluded that the speed of propagation of the recoil kick along the wire was indeed consistent with the speed of light.

Syntonic Jars

The experiment on syntonic jars was first demonstrated at the Royal Institution in 1889 (Lodge, 11). In "Signalling Through Space....." (12) he describes the loops of wire (Fig. 7) as of "about a yard in diameter ... situated about two yards apart" and "giving some 30 or 40 swings before damping has a serious effect". Sparks at A, which need not be long, will induce sparking across a small gap in a piece of tinfoil at B, nearly connecting the inner and outer foils of the Leyden jar, when the slider S has been adjusted to produce resonance between the two circuits. He suggested that these were inefficient Hertz resonators (although he recognised that at this distance the coupling would be magnetic) which could be "opened out" to form the more efficient Hertz radiator. Efficiency was not required here, however, as circuit damping would have spoilt the syntony demonstration. This trade-off between efficient radiation and sharp tuning, although inevitable in a single circuit, later formed an intellectual barrier for Lodge (Aitken, 13).

The syntonic jars experiment formed the basis of his syntony patent of 1897 which established the concept of being able to select one transmission from amongst many by virtue of their different frequencies. Simply tuning a receiver to a transmitter to obtain for example, maximum range, was not a new idea and was explicit in the experiments of Hertz and in Marconi's first patent (14). Lodge's mental block consisted of not separating the functions of radiation and reception from those of transmitter and receiver tuning. Thus he later insisted on Hertzian type dipole radiators because the Marconi type aerial and earth would produce too much damping (because of efficient radiation) for effective syntony. Marconi circumvented this by having the sharp tuning in a circuit only loosly coupled to the aerial, an idea first described by Stone (13).

DETECTION OF ELECTROMAGNETIC WAVES

Athough the basis of generation of electromagnetic waves took a considerable time to be established after the original concept of acceleration of electric current had been formulated, methods for their detection were even less obvious.

Spark Detectors

Hertz used small spark gaps sometimes with a microscope and this represented the first systematic application of a detector. Unfortunately this requires a potential difference of at least 300V to occur and is therefore not very sensitive. However if the duration is very short it need not imply a large amount of energy. In this respect it is well adapted to spark excitation because it occurs very rapidly.

The birth date of the spark as a quantitative detector may be considered to be 25th October 1886 when Hertz obtained a spark micrometer and a period of intense experimentation followed (2). This started with experiments on induction and resonance between two circuits, through experiments on refraction and culminated in interference and standing waves in free space published in 1888. It is little wonder that he was complaining about "glitter and trouble with his eyes" in February 1889.

Coherers

1889 also represents the year in which Lodge noticed the phenomenon of cohesion during experiments on lightning in which metallic balls in light contact would stick together after the passage of a spark (Lodge, 12) and became electrically conducting only after such a spark. Initially he reserved this name for single point devices and only later were "Branly tubes" and "borings tubes" also called coherers. There were several earlier precedents for related devices including a telegraphic lightning protector patented by C. and S.A. Varley in 1866 using powdered carbon. Hughes had also used a carbon coherer in his early demonstration of radio transmission in 1879 although it had not been accepted for what it clearly was and therefore remained unpublished until 1899 (Fahie, 16).

The physical mechanism of the coherer is still not completely understood (Phillips, 17, Andrews, see 4). In the case of Lodge's original observation it could be simply welding of the spheres together but for the present purposes it is sufficient to consider it as a breakdown of an insulating oxide layer. In all coherers apart from the carbon one and some versions of the Italian Navy coherer, it is necessary to restore it to its sensitive condition by tapping it by some means. Many of the early radio patents were devoted to variants of this process, based either upon demand as Marconi preferred, or regularly as Lodge mostly employed.

Lodge developed four versions of coherer (12). After experimenting with filings tubes as devised by Branly, he came to prefer his borings tube which used rather large iron or steel borings (Fig. 8). He also used an adjustable single needle point in contact with a spring (Fig. 9). This was thought to be more sensitive but less reproducible than multiple contact types, and had the advantage that it was easy to decohere by running a cogwheel or cam against its far end. Following a suggestion of FitzGerald, Lodge devised a spiral spring and small aluminium plate coherer (Fig. 10) which was used in his 1894 lectures. The ultimate and probably the best coherer was devised by Robinson and patented by Lodge, (Muirhead and

Robinson 18) in 1902. This consisted in a thin steel disc rotating slowly in blob of mercury covered by a layer of oil (Fig. 11). This normally maintains a thin insulating layer of oil between the mercury and steel until broken down by a potential difference of about 0.5V (most other coherers require about 2V for operation). As the disc continues to rotate the oil layer is restored in the absence of a sustained signal. Marconi had experimented intensively and settled on a mixture of nickel and silver filings between closely spaced electrodes in an evacuated glass tube (Fig.12). This design used with an electromagnetic decoherer continued until he devised the magnetic detector in 1902 (Marconi, 19). Although somewhat less sensitive, it proved extremely reliable in maritime service and served the spark era to its end (Fig. 13). Electrolytic detectors (Fig. 14) were however also reliable and in extensive use abroard. These worked by nonlinear conduction of a very fine point electrode generally in an acid solution (17).

DEVELOPMENT OF RADIO COMMUNICATION

Over most of the period considered, Lodge put his preferred assistant, Benjamin Davies, to work on an inductive "wireless" telegraphy system whilst Edward Robinson worked on radio (5). The first serious suggestion of the communication potential of radio was probably by Alexander Pelham Trotter for the Navy in 1891 (Pocock, 20), and an article in "The Fortnightly Review" by William Crookes in February 1892 was both very wide ranging in its suggestions and very widely read (13,20).

Hertz never envisaged such practical application to his discoveries. Although he had started training as a civil engineer, it was as an experimental physicist that he approached his life's work. It was however his early death at the age of 36 in January 1894 that indirectly got things moving. This motivated Lodge to give a memorial lecture to the Royal Institution in June 1894 (12). After initially planning simply to review Hertz's life and work he decided to take up again the work he had dropped when Hertz's results came out and to include new results of his own.

For these he devised a variety of radiators and coherers (Figs. 8,9,10,15) and demonstrated the effects of a copper "top hat" in prolonging the resonance of a ball radiator and in screening, the effects of light on spark discharges, and refraction and polarisation. The lecture was widely reported (15) and resulted an invitation to lecture at the BA Meeting at Oxford in August 1894.

One member of the audience at the Royal Institution had been the telegraph engineer, Alexander Muirhead, who offered to lend telegraphic equipment for future demonstrations. Thus was Morse signalling demonstrated publically for the first time at the British Association. Lodge, however, presented it in a low key manner as merely an illustration comparable to the reception of electromagnetic energy by the eye. It was not until Marconi was receiving wide publicity, particularly via William Preece, that Lodge began to take the communication possibilities seriously (3). Lodge was certainly not alone in this lacuna as Popov in Russia felt that its value was meteorological, and Righi in Italy saw it like Hertz through the eyes of a physicist (13,20).

Lodge decided, with the encouragement of Muirhead, to try and recover lost ground, firstly by patenting syntony (21), and by the end of 1897 Lodge and Muirhead had secured five patents to Marconi's two (Fleming, 22). With the Muirhead Company involved, many experiments were made between Elmers End and Downe and in 1901 the Lodge-Muirhead Company formed (Lodge and Muirhead, 23). Their equipment was technically very competitive (Fig. 16) but by this time they had lost the iniative to Marconi for maritime use and few other markets were available (13,20).

A great variety of ball spark dischargers were devised, sometimes involving several gaps. In Lodge's ball radiator, probably working in the GHz region, radiator and discharger were combined and it was found necessary to keep the ball and knobs polished for efficient radiation (12). Bose in India moved to even higher frequencies, whereas Marconi moved progressively downward to achieve greater range, and for this greater spark power continued to pay dividends (13). Burning and heat dissipation became a problem, solved first by immersing in oil (Fig. 17) and then by using rotating ball dischargers (22) (Fig. 18). The final version of Marconi rotating disc discharger produced so nearly a continuous wave that he had to break it up using studs to keep the received signal audible (Fig. 19). This was the end of the spark era as by then the Poulsen arc and Alexanderson alternator were taking over (13,20).

By 1911 the international patent situation had become intolerable through infringements and as Marconi's 7777 patent (24) was recognised throughout most of the world as infringing Lodge's syntony patent they were effectively forced to buy out the latter to enforce their other patents (4,13).

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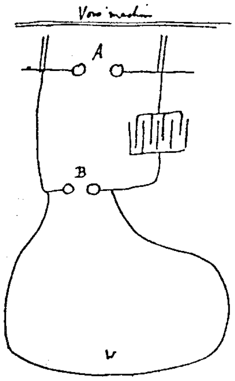

Fig. 1 Alternative path

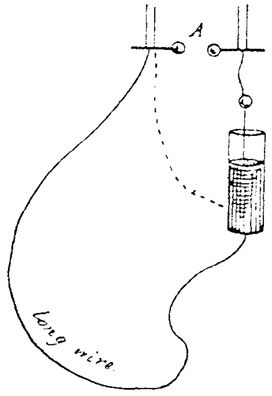

Fig. 2 Overflow

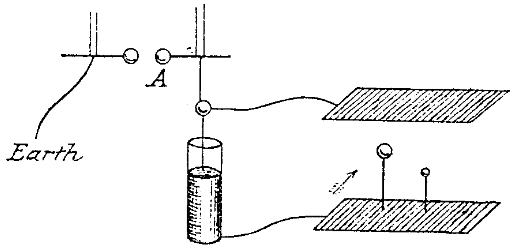

Fig. 3 Lightning as A-spark

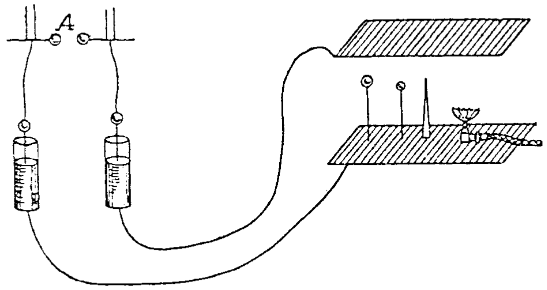

Fig. 4 Lightning as B-spark

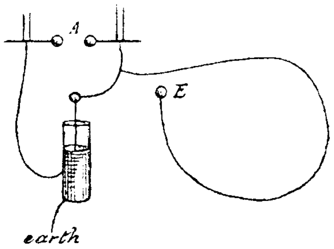

Fig. 5 Side flash

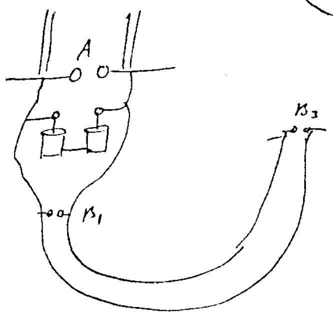

Fig. 6 Recoil kick

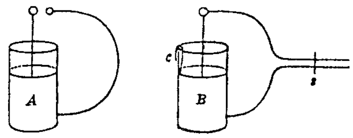

Fig. 7 Syntonic jars

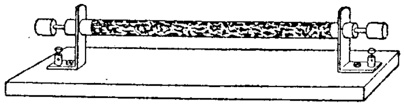

Fig. 8 Borings coherer

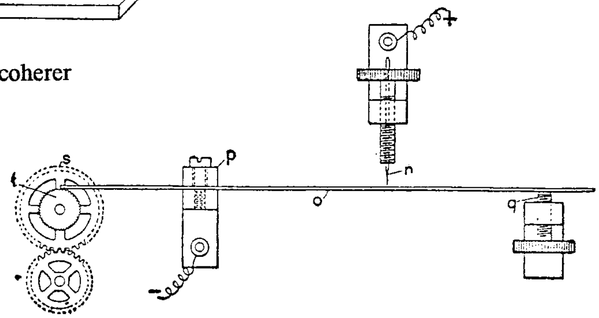

Fig. 9 Single point coherer

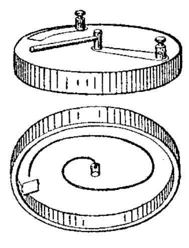

Fig. 10 Spiral wire coherer

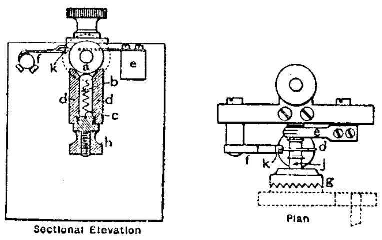

Fig. 11 Mercury wheel coherer

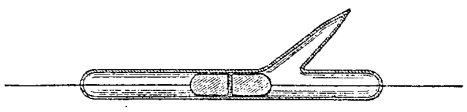

Fig. 12 Marconi coherer

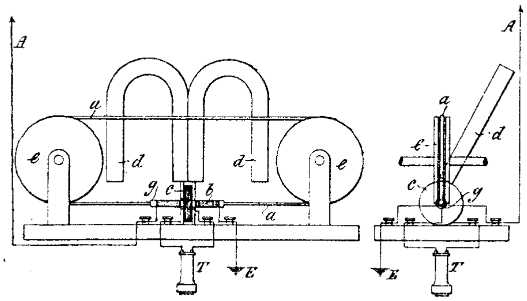

Fig. 13 Magnetic detector

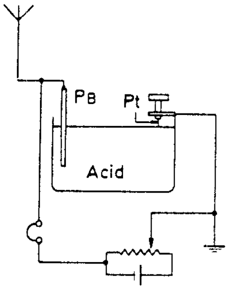

Fig. 14 Electrolytic detector

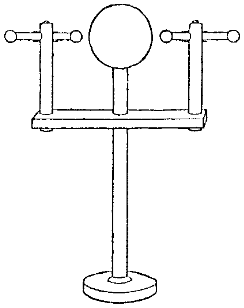

Fig. 15 Ball radiator

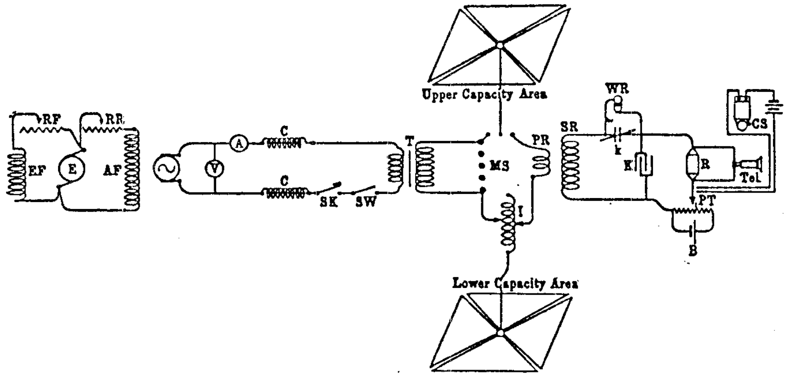

Fig. 16 Lodge-Muirhead System

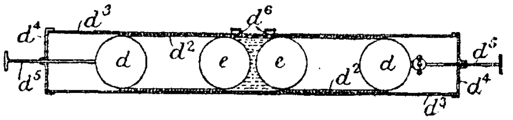

Fig. 17 Marconi oil spark gap

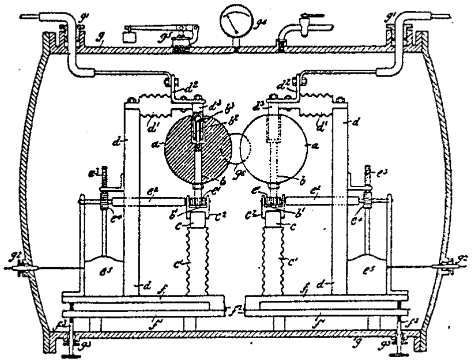

Fig. 18 Fleming rotating ball discharger

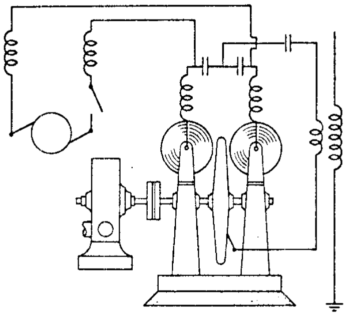

Fig. 19 Marconi rotating disc discharger